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Lemon Balm (*Melissa officinalis* L.) Water Requirement, Crop Coefficients Determination and SIMDualKc Model Implementing

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Authors' contributions

This work was carried out in collaboration between all authors. Authors HG, FM and IA designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Author HG managed the analyses of the study and the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

The crop water requirements and coefficients should be determined for proper irrigation management and scheduling. The present study was conducted to determine water requirements, and single and dual crop coefficients of Lemon balm in a semiarid climate using water balance lysimeters during years 2012 and 2013. For these purposes, twelve water balance drainable lysimeters were used and three lysimeters were applied for grass evapotranspiration while three others were used for bare soil evapotranspiration estimation. Also, in six lysimeters, Lemon balm was planted in two groups including group A in which plant grew continually until the end of flowering stage and the appropriate time was reached for extraction, and group B in which plant was harvested three times, after reaching a height of 12-15 cm. The two year average water requirements of Lemon balm in two lysimeters groups, viz. groups A and B, were determined to be 539 and 415 mm, respectively. Single and base crop coefficients for lysimeters in group A were

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determined to be 0.68, 0.93 and 1.19, 0.42, 0.92 and 1.16, respectively for the initial, development and middle stages of plant. For lysimeters in group B, the average single crop coefficients on first, second and third harvests were determined to be 0.77, 0.77 and 0.81, respectively. In the present study, SIMDualKc model was calibrated and validated by comparing measured and simulated Dual Kc and evapotranspiration (ETc) values. The results showed the model capability and accuracy with low RMSE and MBE and high R^2 = 0.89 for proper irrigation planning and scheduling in semi-arid climates.

Keywords: Drainable lysimeter; single and dual crop coefficient; irrigation planning.

1. INTRODUCTION

Estimating irrigation water requirements accurately is important for water project planning and management [1]. For irrigation scheduling purposes, daily values of crop evapotranspiration (ETc) can be estimated from crop coefficient curves, which reflect the changing rates of crop water use over the growing season if the values of daily reference evapotranspiration (ETo) are available [2]. Where ETc is calculated by using standard agro-meteorological variables and a crop-specific coefficient (Kc), which should take into account the relationship between atmosphere, crop physiology and agricultural practices [3]. A dimensionless crop coefficient (Kc) is multiplied by ETo to compute ETc. In other words, the knowledge of crop coefficient (Kc) is essential for the estimation of water use [4]; It helps in determining the water requirements of the crops according to their growth stage and environmental factors [5].

The concept of Kc was introduced by [6] and further developed by other researchers [7,8,9,10,4,11,12] observed that Kc values can be different from one region to another. In this regard, the crop coefficient values for a number of crops grown under different climatic conditions have been proposed by [8] and many researchers have reported different Kc values in the literature. Different values of Kc reported for alfalfa in the initial, middle and final growth stages based on lysimeter method as 0.71, 1.78 and 1.51, respectively [13]. The crop coefficient and water requirements of saffron studied in Shiraz, southern Iran [14], the water requirements determined as 486 and 670 mm, respectively, during 1998–1999 and 1999–2000. They estimated the saffron crop coefficients during various stages to be between 0.22–0.24, 0.94–1.05 and 0.68–0.78 for preliminary, middle, and final growth stages, respectively. Kc values of watermelon and honeydew were found by using drainable lysimeters [15]. They reported that Kc values were higher than those reported by [4]. Kc and ETc values for Indian corn also were found [16]. They also reported that Kc values were higher than those reported by [4].

The single and dual crop coefficient values for coriandrum and black cumin using drainable lysimeters in a semi-arid region determined and reported by [17,18].

No different factors of irrigation management including water requirements and different crop coefficients have been reported for Lemon balm (*Melissa officinalis* L.) particularly grown in semi-arid climates. The plant is a perennial herb of Lamiaceae family which is mainly cultivated for its characteristic lemon-scented leaves. It is used in making foods and in pharmaceutical and cosmetic industries due to its flavouring and therapeutic properties [19]. Many of the therapeutic effects of this herb are attributed to its leaf essential oil [20]. Lemon balm leaves are often used as herbal teas [21].

The present study was conducted to determine different irrigation management factors of Lemon balm including: (1) Water requirements, (2) Single crop coefficients and (3) Dual crop coefficients of Lemon balm under semi-arid climates. Moreover, as announced by [22], different irrigation scheduling simulation models have been developed during recent decades. However there have been few irrigation scheduling models based on dual crop coefficient approach and its combination with hydrologic extensions for complete water balances.

As reported by [23] SIMDualKc model, developed and fully described by [22,24] has the potential to estimate ETc on a daily basis with separate consideration of soil evaporation and crop transpiration components. They also obtained successful simulation results on summer maize for soil with silt loam texture in North China. This model also has been validated by [25] for citrus with micro irrigation, by [26] for wheat under sprinkler irrigation and by [27] for cotton and winter wheat under furrow irrigation. The data for the purpose of SIMDualKc model simulation include: Soil properties, meteorological data, crop and irrigation data, and capillary rise, deep percolation, runoff and green ground cover. Hence, since the two years of measured lysimetric data were available in this study, the forth purpose was defined to calibrate and validate SIMDualKc model by comparing measured and simulated Dual Kc and evapotranspiration (ETc) values for Lemon balm in a semi-arid climate in order to show model capability for proper and accurate water resources management in medicinal plant. This study is the first on the model application for medicinal plant and no other studies have been reported in the literature.

2. MATERIALS AND METHODS

2.1 Experimental Site and Weather Station, Soil and Irrigation Water Details

The Lysimetric experiments were carried out in two years from 2012 to 2013 from the months of April to the month of July at the Irrigation and Water Resources Engineering Research Lysimetric Station No. 3 located at 47º9′E and 34º21′N, with an elevation of 1319 m (asl), as part of the Campus of Agriculture and Natural Resources of Razi University in Kermanshah, Iran. The region under study has a semi-arid climate. The daily meteorological data were obtained from the regional meteorological station located 100 m off the lysimetric station. Table 1 shows the average two-year meteorological data for the study area. The soil texture in the lysimeters was silty clay composed of different clay, silt and sand percentages. Tables 2 and 3 show the chemical and physical properties of the soil and the chemical components of the irrigation water used in this study. The pressure plate and sampling methods were used to determine θ (fc), θ (pwp) and bulk density in different lysimeters soil depths, respectively.

2.2 Detail of Drainable Lysimeters

In the present study, twelve drainable lysimeters were used with an internal diameter of 1.20 m and a depth of 1.40 m. As reported by [18] the lysimeters were constructed from 3-mm-thick mild steel with internal diameter of 120 cm and a depth of 140 cm. The inside and outside of each lysimeter were painted with epoxy to prevent rusting. Each lysimeter was completely isolated from outside with a special tarry material. The bottoms of lysimeters were inclined toward the center to collect extra drainable water. In order to drain water from the bottom of each lysimeter, an intake screen of stainless steel with mesh size of 0.2 mm was used. A 10-cm layer of gravel as well as a 10-cm layer of sand were placed at the bottom. A pipe with diameter of 2.50 cm along with a control gate valve were placed at the bottom of each lysimeter to guide drained water towards a graded container to measure excessive water. Silty clay soil consisting of 54, 42.3 and 3.7% clay, silt and sand, respectively, was used in all lysimeters. All lysimeters were filled with air-dried soil. The layer was manually compacted to reach a bulk density of 1.30 gcm^{-3} according to [28] method. Soil field moisture characteristic curves was developed using [29] method.

2.3 Soil Moisture Measurement

A TDR system (Trime-Fm with P2G probes) was used for soil moisture measurements. TDR probes were 0.60 cm in diameter and 16 cm length and installed in all lysimeters at 6 different depths of 20, 40, 60, 80, 100 and 120 cm. The irrigation was carried out in all lysimeters after 30% depletion of available soil moisture in order to avoid any water stress during the growing period.

2.4 Actual and Potential Evapotranspiration

In this study, three lysimeters were used to estimate grass evapotranspiration; Also, three other lysimeters were used to estimate bare soil evaporation. In other six lysimeters, Lemon balm was planted in two groups including group A (G_A), whose growth continued up to 70% of flowering stage and appropriate time for extraction and group B (G_B), which were harvested three times after reaching a height of 12-15 cm was planted. The actual evapotranspiration or crop evapotranspiration (ETc), bare soil evaporation (Es) and reference evapotranspiration (ETo) were calculated each by using Eq. (1) in their own lysimeters separately as follows:

$$\text{ETc or ES, ETo} = P + I - D - R - \Delta s \qquad (1)$$

Where, P is precipitation (mm); I is irrigation (mm); D is the water drained (mm); R is runoff (mm) and ΔS represents the changes in soil water storage during the period for which ETc, ETo or ES were computed (mm). The precipitation was measured with a rain gauge *in situ*. The irrigation (I), D and R for the lysimeters were measured with a precession graded container and rain gauge. The changes in soil moisture were obtained from soil moisture readings at different depths. Daily meteorological data including: Minimum and maximum temperatures, sunshine hours, wind speed and average relative humidity were also collected from a regional meteorological station.

2.5 Single and Basal Crop Coefficient

The single crop coefficient was calculated using measured crop evaptranspiration (ETc) with the calculated reference evapotranspiration (ETo) in Eq. (2):

$$Kc = ETc/ETo \quad (2)$$

where ETc = crop ET (mm); ETo = reference crop ET (mm); and Kc = crop coefficient.

The dual crop coefficients were measured only for lysimetrs in groups A, according to those proposed by [4] in FAO 56. The following procedures were applied:

$$Kc = Kc\ basal + Kc\ soil\ evaporation \quad (3)$$

$Kc_{initial}$ = Kc basal tabulated

$$Kc\ basal = [Kc_{initial} + 0.04(U_2 - 2) - 0.004(RH_{min} - 45)]\ (h/3)^{0.3} \quad (4)$$

Where RH_{min} = minimum relative air humidity (percentage); h =crop height (m); u_2 = wind speed at 2 m above ground surface (m s^{-1}).

The sum of Kcb and Ke (Kc soil evaporation) in Eq. (3) cannot exceed maximum value (Kc max), which defines an upper limit on the evaporation and transpiration from any cropped surface based on the available energy.

$$K_{c\max} = \max\{\{1.2 + [0.04(U_2 - 2) - 0.004(RH_{min} - 45)](h/3)^{0.3}\}, (K_{cb} + 0.05)\} \quad (5)$$

Where h represents mean maximum plant height (m) and max indicates the selection of the maximum value within the brackets {}.

Table 1. Meteorological data for growing period 2012-2013

Year	Month	Mean temperature (C°)	Mean relative humidity (%)	Mean wind speed (m/s)	Mean monthly sunshine (h)	Total precipitation (mm)
2012	April	11.8	53.9	7.1	6.9	45.7
	May	18.4	36.5	7.7	8.3	17.9
	June	24.8	21.4	7.9	9.7	0.0
	July	28.1	19.6	7.6	10.2	0.0
2013	April	13.4	42.5	7.3	7.3	10.7
	May	15.1	54.2	8.4	5.3	63.1
	June	23.3	27.4	7.4	9.2	0.0
	July	29.1	14.7	7.4	11.6	0.0

Table 2. Physical and chemical properties of soil

Soil texture	Sand (%)	Silt (%)	Clay (%)	Ec (ds/m)	Θ(Fc) (%)	Θ(PWP) (%)	pH	Bulk density (gr/cm³)	Soil depth (cm)
	3.7	42.3	54	0.61	27.6	17.2	7.63	1.3	0-30
Silty				0.61			7.61		30-60
Clay				0.59			7.73		60-90
				0.58			7.73		90-120

Table 3. Physical and chemical properties of irrigation water

$SO2^{-}$ (Meq/L)	CL^{-} (Meq/L)	$HCO3^{-}$ (Meq/L)	$CO3^{2-}$ (Meq/L)	TDS (Meq/L)	pH	EC (dS/m)	Anions (Meq/L)	Mg^{2+} (Meq/L)	Na+ (Meq/L)	Ca^{2+} (Meq/L)	Cations (Meq/L)
1.25	1.90	6.15	0	390	7.2	0.61	9.30	3.1	1.15	5.05	9.30

$$f_c = \left(\frac{K_{cb} - K_{c\min}}{K_{c\max} - K_{c\min}} \right)^{(1+0.5h)} \quad (6)$$

Where fc = effective fraction of the soil surface covered by crop canopy and limited to [0–0.99], Kc_{min} = minimum Kc for bare soil with no ground cover (≈0.15), and h = mean plant height. Therefore, the fraction of the soil where is exposed to solar radiation and air ventilation and from which the majority of Es occurs is expressed as (1−fc).

2.6 Simdualkc Model

The model was first calibrated and validated for lysimetric data obtained in 2012 and 2013. The simulation procedures were performed using soil, crop, irrigation and weather data which were collected during both crop seasons. Soil data collected at the experimental site included basic soil hydraulic properties and soil water contents measured at different depths within effective rooting zones throughout the crop seasons. Crop data included observed crop growth stage dates, crop cover parameters, crop heights and root depths from planting to harvesting phases. Climatic data of SIMDualKc model required to compute soil water balance included reference evapotranspiration, (ETo) which was previously computed, daily precipitation, minimum relative humidity (RHmin) and wind speed at 2 meters height (u_2). Leaf area index (LAI) was measured during the study and after each 5day period with portable leaf area meter called LAI-2000, USA. The values were also used to estimate grand cover fraction (fc). The calibration procedures consisted of adjusting parameters including depletion fraction (p), total evaporable water (TEW), readily evaporable water (REW) and thickness of the evaporation soil layer (Ze). The first set of the parameters was estimated in accordance with standard values in SIMDualKc model. Then, a trial and error procedure was initiated to select values until differences between observed and simulated values were approximately minimized. The validation of the model consisted of using calibrated values to simulate lysimetric experiments. The statistical means were subsequently applied to assess the goodness fit of SIMDualKc model projections with the observations according to procedures as suggested by [24].

2.7 Model Comparison

SIMDualKc model was evaluated by comparing observed and simulated Dual Kc values over time for the region under study. The method suggested by [30,31] were used for statistical analyses. The following equations were used to compute the regression coefficients (r), root mean square error (RMSE), mean bias error (MBE) and t-statistic test (t).

$$-1 \le r \le 1 \quad (7)$$

$$r = \frac{\sum_{i=1}^{n} (x - \bar{x})(y - \bar{y})}{\sqrt{\sum_{i=1}^{n} (x - \bar{x})^2 \sum_{i=1}^{n} (y - \bar{y})^2}} \quad (8)$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n} d_i^2}{n}} \quad (9)$$

$$MBE = \sum_{i=1}^{n} \frac{d_i}{n} \quad t = \sqrt{\frac{(n-1)\,MBE^2}{RMSE^2 - MBE^2}} \quad (10)$$

Where, x = the measurement value, $\bar{x}$ = the mean measurement value, y = the predicted value, $\bar{y}$ = the mean predict value, di = difference between i^{th} predicted and i^{th} measured values, n = number of data pairs i.

3. RESULTS AND DISCUSSION

3.1 Crop Development Stages

The crop growing season was divided into initial, developing and middle growing stages. Tables 4 and 5 show the lengths of crop development stages for both lysimeters groups A and B, respectively. The initial stage refers to crop germination and transplanting. It also refers to when the soil surface is not covered by the crop (canopy cover< 10%). The crop development stage indicates the vegetative period of the crop from the end of initial stage to full canopy cover inclusive (canopy cover 70–80%). The mid-season stage represents the period between full ground cover to 70% of flowering and appropriate time for extraction. Total duration of different Lemon balm growing periods during 2012 and 2013, in two lysimeters groups A and B, are shown in Tables 4 and 5. The total growing periods of Lemon balm were determined to be 104 and 92 days in 2012 and 2013, respectively.

3.2 Actual and Potential Evapotranspiration and Single Crop Coefficients

The lysimeteric results in two years indicated that the daily reference evapotranspiration ranged from 2.6 to 8.2 mm per day. The volume of water balance components consisting of mean monthly irrigation, precipitation, variation of soil water contents, drainage and finally, mean actual ET values during the experimental study for the two lysimeters groups A and B, are given in Tables 6 to 9. The mean seasonal ETc of the cropping season for two lysimeters groups A and B in 2012 were slightly higher with ETc- G_A = 576 mm and ETc- G_B = 452mm than those in 2013 with ETc-G_A = 502 mm and ETc-G_B = 377mm. The average water requirements of Lemon balm in two lysimeters groups A and B were determined to be 539 and 415 mm, respectively. A summary of potential evapotranspiration (ETO), actual evapotranspiration (ETc) and Kc values for Lemon balm for a 10-day period in 2012 and 2013 are given in Table 10. As shown in Table 10, the values of ETc and Kc in 2012 and 2013 during the third set of 10-day records were lower than the other decades. In other words, ETc and Kc values increased from the initial stage to the mid season stage. This was mainly attributed to lower canopy cover at the early stage of the crop growth where similar changes can be seen in Table 11 after each harvesting period leading to lower canopy cover of the crop in group A. As results in Table 12 indicate, during the initial, developing and middle growth stages, the single crop coefficients of Lemon balm for lysimeters in group A were determined to be 0.66, 0.89 and 1.14 for 2012 and 0.70, 0.96 and 1.23 for 2013, while the average values for both years were determined to be 0.68, 0.93 and 1.19, respectively. Also, according to Table 13, during the first, second and third harvesting stages, the single crop coefficients of Lemon balm for lysimeters in group B were determined to be 0.75, 0.75 and 0.80 for 2012 and 0.79, 0.79 and 0.82 for 2013, and the average values for both years to be 0.77, 0.77 and 0.81, respectively. The differences in crop coefficient values are probably due to daily water balance and climatic conditions. The actual daily crop coefficients and linear Kc values for Lemon balm obtained from lysimetric data, for two lysimeters including groups A and B, are presented in Figs. 1 and 2 during 2012 and 2013, respectively.

Table 4. Date and length of lemon balm growth stages for lysimeters in group A

Growth stage	2012		2013		Average duration (days)
	Date	Duration (days)	Date	Duration (days)	
Initial	14/04/2012 to 22/04/2012	9	14/04/2013 to 24/04/2013	11	10
Development	23/04/2012 to 23/06/2012	62	25/04/2013 to 14/06/2013	51	56
Mid	24/06/2012 to 26/07/2012	33	15/06/2013 to 14/07/2013	30	32
Total growing period	104		92		98

Table 5. Date and length of lemon balm growth stages for lysimeters in group B

Harvest times	2012		2013		Average duration (days)
	Date	Duration (days)	Date	Duration (days)	
First harvest	14/04/2012 to 24/05/2012	41	14/04/2013 to 22/05/2013	39	40
Second harvest	25/05/2012 to 26/06/2012	33	23/05/2013 to 18/06/2013	27	30
Third harvest	27/06/2012 to 26/07/2012	30	19/06/2013 to 14/07/2013	26	28
Total growing period	104		92		98

Table 6. Volume balance components for lysimeters in group A, during 2012

Month	Mean irrigation (mm)	Precipitation (mm)	Variations of soil water content (mm)	Mean drainage (mm)	Crop evapotranspiration (ETc) (mm)
From April 14	33.04	6.10	-2.17	6.94	30.03
May	146.06	17.90	2.42	33.59	132.79
June	221.62	0.00	28.61	48.76	201.48
To July 26	233.05	0.00	23.09	44.28	211.86

Table 7. Volume balance components for lysimeters in group B, during 2012

Month	Mean irrigation (mm)	Precipitation (mm)	Variations of soil water content (mm)	Mean drainage (mm)	Crop Evapotranspiration (ETc) (mm)
From April 14	28.91	6.10	0.80	5.78	30.03
May	158.62	17.90	-7.25	36.48	132.79
June	210.51	0.00	35.17	44.21	201.48
To July 26	222.16	0.00	31.92	42.21	211.86

Table 8. Volume balance components for lysimeters in group A, during 2013

Month	Mean irrigation (mm)	Precipitation (mm)	Variations of soil water content (mm)	Mean drainage (mm)	Crop evapotranspiration (ETc) (mm)
From April 14	48.97	4.60	-1.02	9.79	42.75
May	127.22	63.10	-47.35	29.26	113.71
June	245.13	0.00	23.77	51.48	217.42
To July 14	150.21	0.00	6.71	28.54	128.38

Table 9. Volume balance components for lysimeters in group B, during 2013

Month	Mean irrigation (mm)	Precipitation (mm)	Variations of soil water content (mm)	Mean drainage (mm)	Crop evapotranspiration (ETc) (mm)
From April 14	48.99	4.60	-1.03	9.80	42.75
May	141.03	63.10	-57.99	32.44	113.71
June	213.99	0.00	48.37	44.94	217.42
To July 14	135.24	0.00	18.84	25.70	128.38

Table 10. 10-day potential evapotranspiration, crop evapotranspiration, and average crop coefficient of lemon balm in lysimeters in group A, in 2012 and 2013

10 – day record	2012			2013			Average of both 2012 and 2013		
	ETc	ETo	Kc	ETc	ETo	Kc	ETc	ETo	Kc
1	14.44	22.98	0.65	24.90	35.96	0.69	19.67	29.47	0.67
2	24.81	35.59	0.70	26.61	35.45	0.76	25.71	35.52	0.72
3	33.92	40.80	0.84	30.99	37.98	0.82	32.45	39.39	0.83
4	51.53	53.11	0.99	37.21	37.44	1.01	44.37	45.28	1.00
5	48.24	53.36	0.92	47.43	46.27	1.04	47.84	49.81	0.97
6	62.33	68.02	0.92	63.88	55.94	1.15	63.10	61.98	1.02
7	67.32	67.02	1.02	72.68	63.80	1.14	70.00	65.41	1.07
8	76.20	63.80	1.22	87.42	69.54	1.26	81.81	66.67	1.23
9	74.28	70.68	1.07	90.70	75.22	1.21	82.49	72.95	1.14
10	85.97	74.79	1.19	20.46	14.04	1.46	52.89	50.73	0.67
11	37.10	35.76	1.04	-	-	-	-	-	-

Table 11. 10- day potential evapotranspiration, crop evapotranspiration, and average crop coefficient of lemon balm in lysimeters in group B, in 2012 and 2013

10 – day record	2012			2013			Average of both 2012 and 2013		
	ETc	ETo	Kc	ETc	ETo	Kc	ETc	ETo	Kc
1	13.94	22.98	0.62	25.04	35.96	0.70	19.49	29.47	0.66
2	23.67	35.59	0.66	25.36	35.45	0.73	24.51	35.52	0.69
3	32.41	40.80	0.80	30.00	37.98	0.80	31.20	39.39	0.80
4	45.93	53.11	0.88	34.64	37.44	0.93	40.28	45.28	0.90
5	35.93	53.36	0.68	34.83	46.27	0.76	35.38	49.81	0.72
6	50.33	68.02	0.74	44.25	55.94	0.80	47.29	61.98	0.77
7	51.35	67.02	0.78	49.64	63.80	0.78	50.50	65.41	0.77
8	48.57	63.80	0.77	56.74	69.54	0.82	52.66	66.67	0.79
9	55.33	70.68	0.79	64.63	75.22	0.86	59.98	72.95	0.82
10	64.34	74.79	0.87	12.68	14.04	0.90	37.40	50.86	0.74
11	29.75	35.76	0.83	-	-	-	-	-	-

Table 12. Average lemon balm single crop coefficients in lysimeters in group A

Growth stage	2012	2013	Average
Initial	0.66	0.70	0.68
Development	0.89	0.96	0.93
Mid	1.14	1.23	1.19

Table 13. Average lemon balm single crop coefficients in lysimeters in group B

Harvest times	2012	2013	Average
first harvest	0.75	0.79	0.77
Second harvest	0.75	0.79	0.77
Third harvest	0.80	0.82	0.81

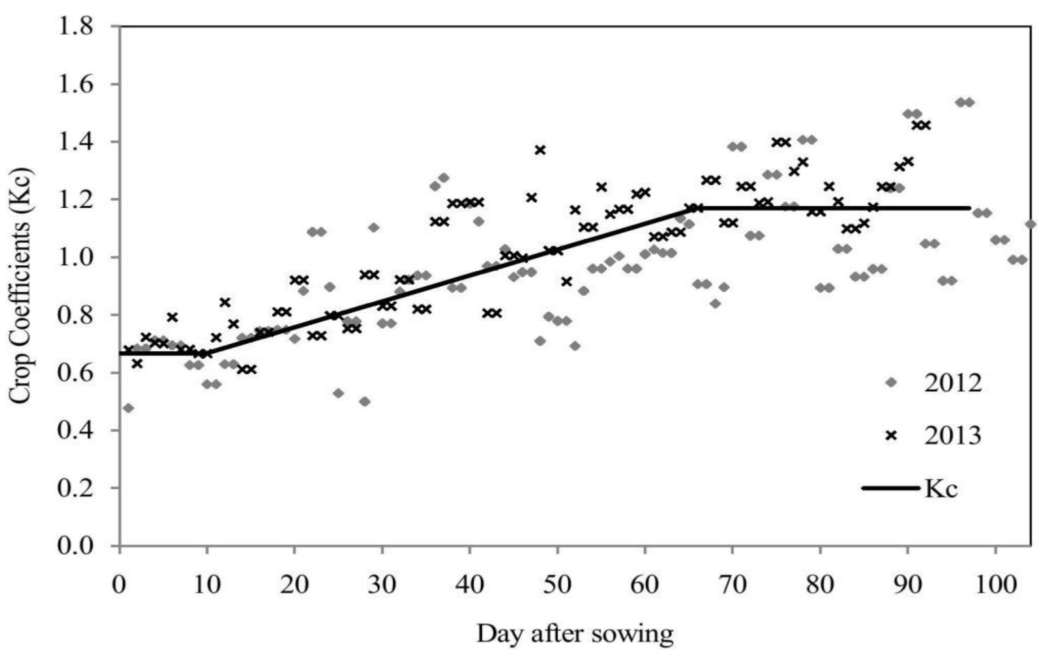

Fig. 1. Actual daily crop coefficient and linear crop-specific coefficient (Kc) values for Lemon balm stages in lysimeters in group A

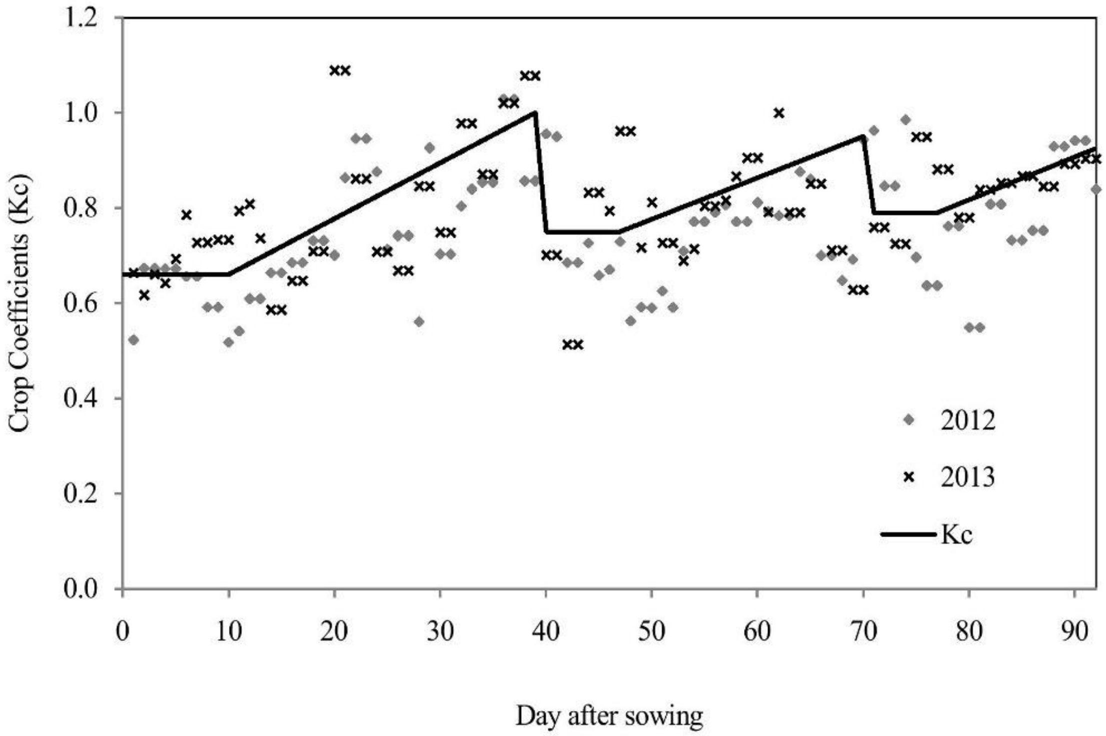

Fig. 2. Actual daily crop coefficient and linear crop-specific coefficient (Kc) values for lemon balm stages in lysimeters in group B

3.3 Dual Crop Coefficient

During 2012 and 2013, the values of basal crop coefficients and evaporation were obtained from soil and dual daily crop coefficients for the three growth stages (i.e., initial, crop development and mid-season growth) of Lemon balm for lysimeters in group A. Table 14 shows the values of basal crop coefficients during the growing periods of Lemon balm. Also, the values of single and dual crop coefficient variations for 2012 and 2013 are presented in Figs. 3 and 4, respectively. As shown in Table 14 and Figs. 3 and 4, the values of the basal crop coefficient (i.e., transpiration values) gradually increased, and the highest values were obtained in midseason stage. During the initial stage, when the plant green coverage was low, evaporation from the soil was the highest while during as the plant grew, it gradually decreased. Finally, the lowest values were obtained in mid-season of plant growing period. In the initial stage, Es value was the predominant component of ETc, and Kcb, and single-Kc were constant representing an average rate of Es from a dry soil surface. During crop development stage, both values of Kcb and single-Kc increased. This was due to the development and expansion of leaves surfaces. As the number and size of plant leaves increased, the number of stomata increased as well, while the increase of transpiration rate was directly related to Etc values [4]. At mid-season stage, the full canopy cover grew and transpiration rate was typically at a potential (i.e., maximum) rate. The dual-Kc was responsive to the surface wetness and increases whenever the soil surface was moist. As shown in Table 14, the average values of basal crop coefficients for initial, developing and middle stages were determined to be 0.42, 0.92 and 1.16 respectively.

Table 14. Average basal crop coefficient of lemon balm during growth stages

Year	Initial	Developing	Middle
2012	0.40	0.91	1.09
2013	0.43	0.93	1.23
Average	0.42	0.92	1.16

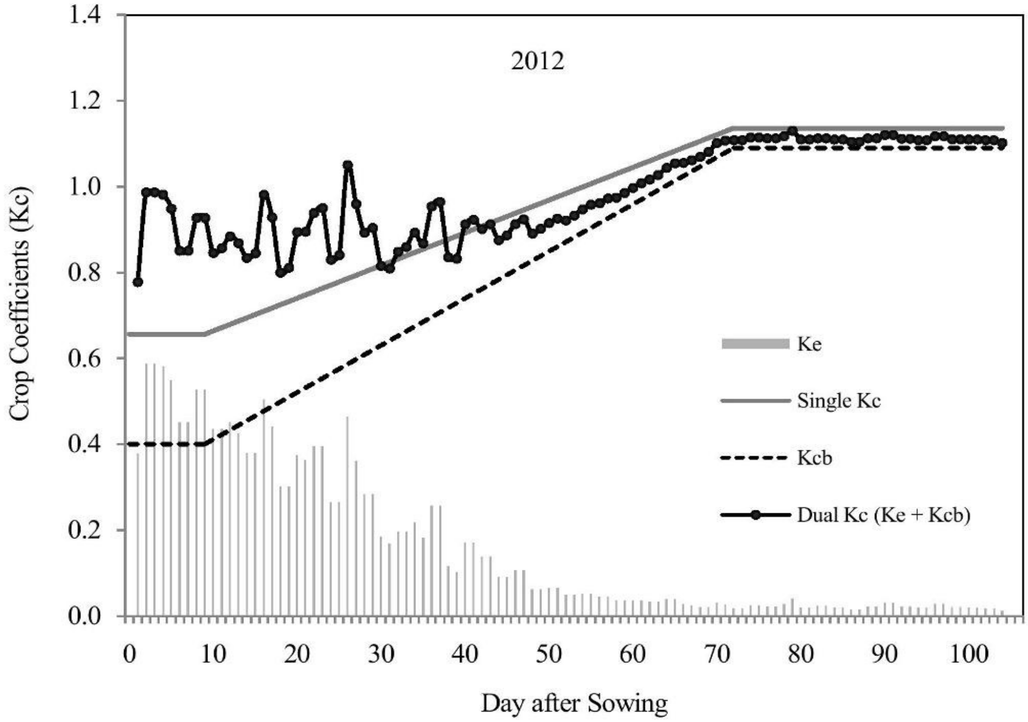

Fig. 3. Single and dual lemon balm crop coefficient in 2012

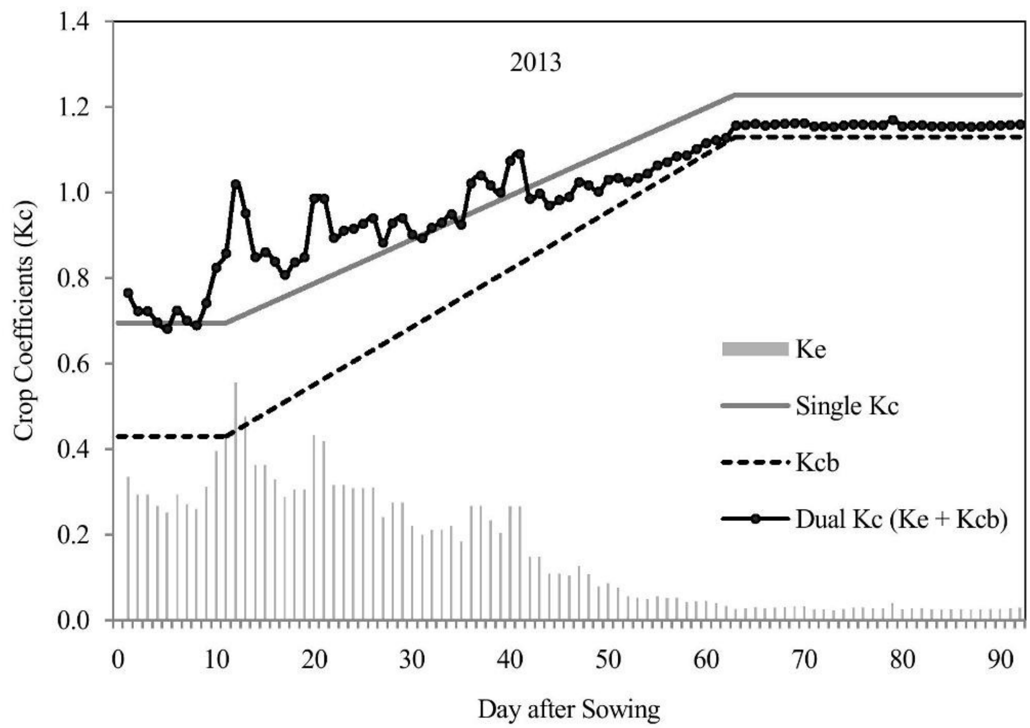

Fig. 4. Single and dual lemon balm crop coefficient in 2013

3.4 Model Comparison

The standard values for some parameters including TEW, REW and p are required to run model after a calibration-validation procedure or trial and error proposed by [24]. The proper adjustments to the values including REW, TEW and Ze with 11 mm and 38 mm, and Ze = 0.15 m were considered for simulations procedures, respectively. The initial depletion in the evaporable layer was set at 20% of TEW for both 2012 and 2013 seasons. The R^2, RMSE, MBE and t-test statistical methods were used to compare the measured Dual Kc values with simulated values. The comparisons between simulated and measured Dual Kc in the calibration (2012) and validation (2013) years are given in Table 15 and Fig. 5. Based on RMSE and MBE values given in Table 5, the negative sign of the MBE indicates that the computed Dual Kc were lower than the Dual Kc measured by the lysimeter and the positive MBE shows overestimation of the lysimeter ETo values, while absolute value was an indicator of method performance Table 15. According to [31], the performance of each method in the present study was based on t values. Lower t-values show better performance of the method indicating that the differences between the measure and the estimated values are lower. Fig. 5 shows a reasonable Dual Kc fitness between the measured and the model simulated values as presented with different fitting indicators in Table 15. It can be seen that R^2 are between 0.90 and 0.92, the estimation errors RMSE and MBE ranging between (0.05-0.09) and (-0.02-0.02), respectively. All indicators showed the capability of the model for accurate prediction of Dual Kc for Lemon balm. In addition, a comparison was made between model simulated and ET_C measured crop evapotranspiration (ETc), the results of which are shown in Figs. 6 and 7 and Table 16. The results suggest a good agreement between simulated and measured daily ETc values. The values of R^2 were between 0.83 and 0.95 and the results indicate a small overestimation of the model simulations during both years of the study. However, the estimated errors were acceptable with RMSE ranging between (0.57-1.06) mm/d, MBE ranging (-0.11-0.26 mm/d) and R/t ranging between (0.35-0.53), respectively.

A few numbers of studies have been reported on SIMDualKc Model simulation and validation. The model evaluated for citrus under micro irrigation systems [25]. Also, the model was validated and calibrated by [26] and [32] for wheat crop under sprinkle and surface irrigation, respectively. All the studies have reported been to produce good predictions of available soil water by the model. SIMDualKc Model is appropriate to simulate the soil water balance adopting dual Kc approach and may be further used to develop improved irrigation schedules for the winter wheat–summer maize crop sequence in North China as reported by [33]. The appropriate basal crop coefficients for maize through the calibration and validation of the model using various treatments of maize irrigated with sprinkler and drip methods under full and deficit irrigation and cropped with organic mulch as reported by [34]. They suggested that the corresponding results showed a good agreement between the simulated and observed available soil water through the season, with regression coefficients of 0.99–1.02 and the root mean square error ranging 2.0–3.3% of the total available water. No studies are yet available in literature on the simulation and validation of SIMDualKc Model for Lemon balm in a semi-arid climate for further comparison, albeit the results of the model simulation and validation found in this study are in agreement with those reported by other researches above.

Table 15. Correlation between the simulated dual Kc and the measured values in 2012-2013

Year	RMSE	MBE	R^2	R/t
2012 (Calibration)	0.05	0.02	0.90	0.27
2013 (Validation)	0.09	-0.02	0.92	0.46
Average	0.07	0.0	0.91	0.37

Table 16. Correlation between the simulated evapotranspiration and the measured values in 2012-2013

Year	RMSE	MBE	R^2	R/t
2012 (Calibration)	1.06	0.26	0.83	0.35
2013 (Validation)	0.57	-0.11	0.95	0.53
Average	0.82	0.08	0.89	0.44

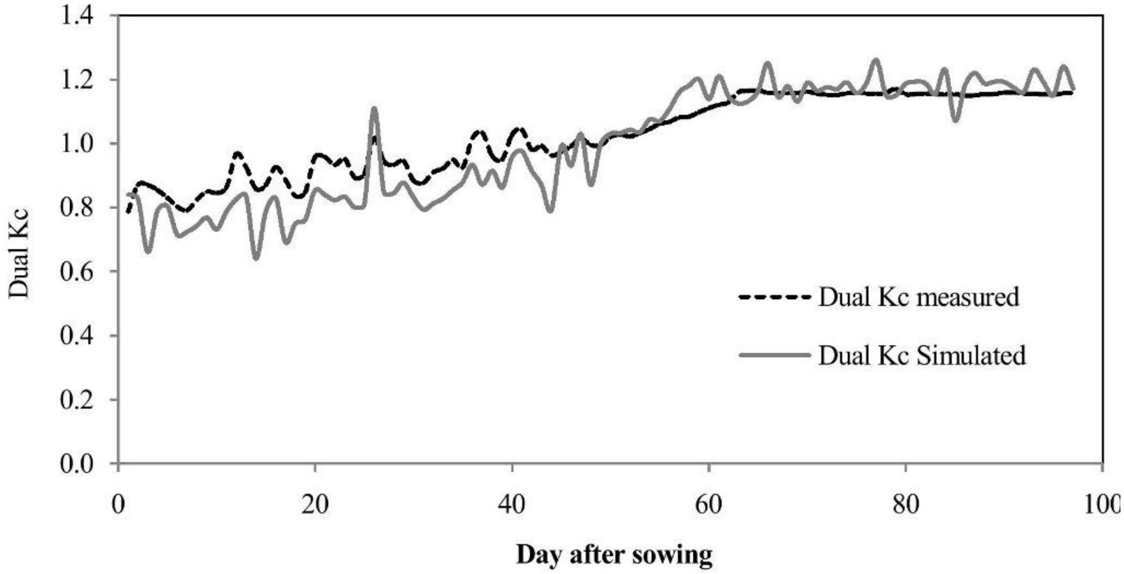

Fig. 5. Comparison between simulated and measured dual Kc

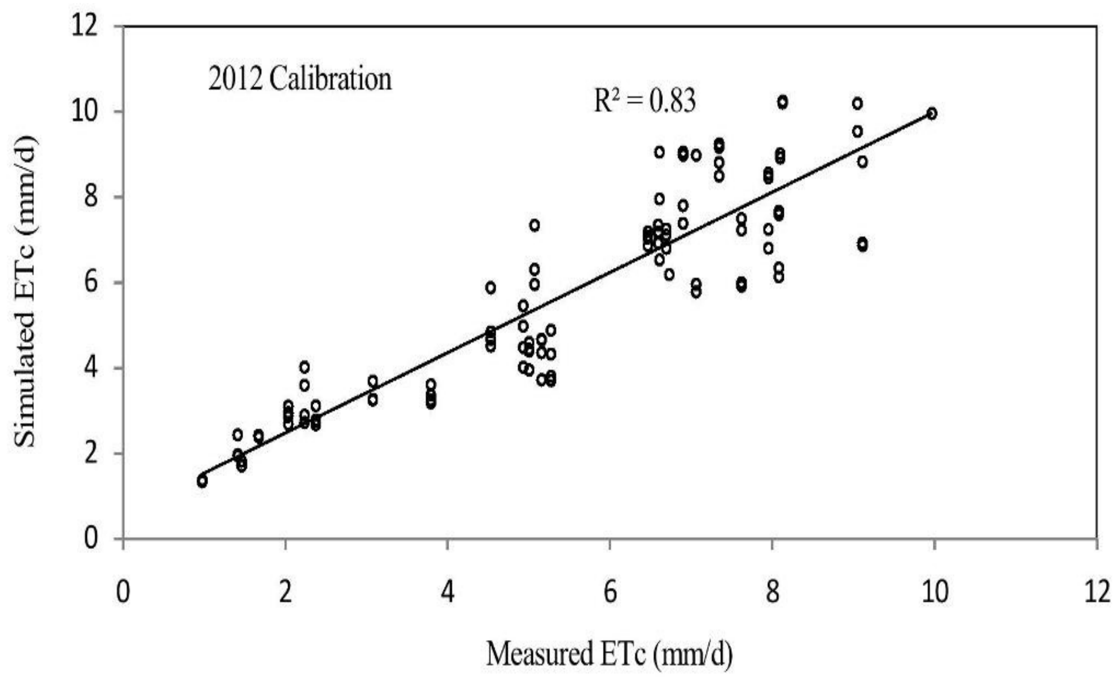

Fig. 6. Comparison between simulated and measured evapotranspiration (ETc) in 2012

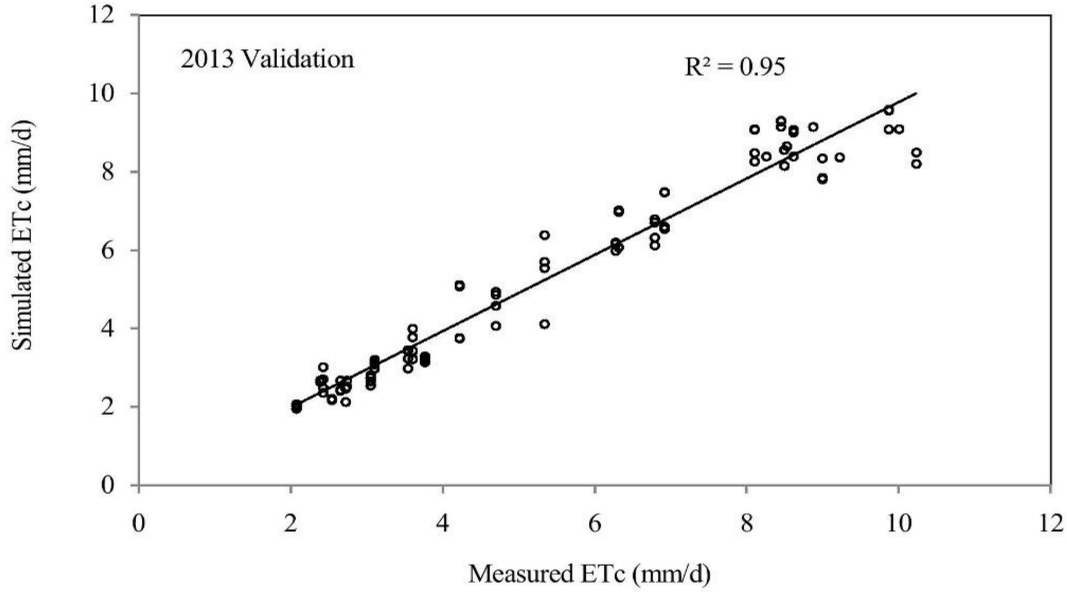

Fig. 7. Comparison between simulated and measured evapotranspiration (ETc) in 2013

4. CONCLUSION

Crop coefficients for different medical plants are still unknown and the determination of irrigation management parameters for medicinal plants have not been addressed by researchers for different climates. The seasonal ETc of Lemon balm under two planting conditions including group A, during which the planting growth continued up to 70% of flowering and appropriate time for extraction and group B, during which plants were harvested three times after reaching a height of 12-15 cm, were investigated in 2012 and 2013. The results showed that the total water requirements in group A, single and dual crop coefficients for initial, development, middle stage of Lemon balm, were 539 mm and 0.68, 0.93 and 1.19, 0.42, 0.92 and 1.16, respectively. Also, the total water requirements and single coefficients in group B were determined to be 415 mm and 0.77, 0.77 and 0.81, respectively. Furthermore, SIMDualKc model was calibrated and validated by lysimetric data, which were obtained during two years of investigations. The results of all statistical parameters showed the capability of the model to produce accurate predictions of Dual Kc for Lemon balm in semi-arid climates. Moreover, a comparison between model simulated and measured crop evapotranspiration values (ETc) was made and the results indicated a good agreement between simulated and measured daily ETc values. Therefore, from the results, one can suggest that SIMDualKc model is capable of estimating all irrigation management parameters with high accuracy and speed in semi-arid climates.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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